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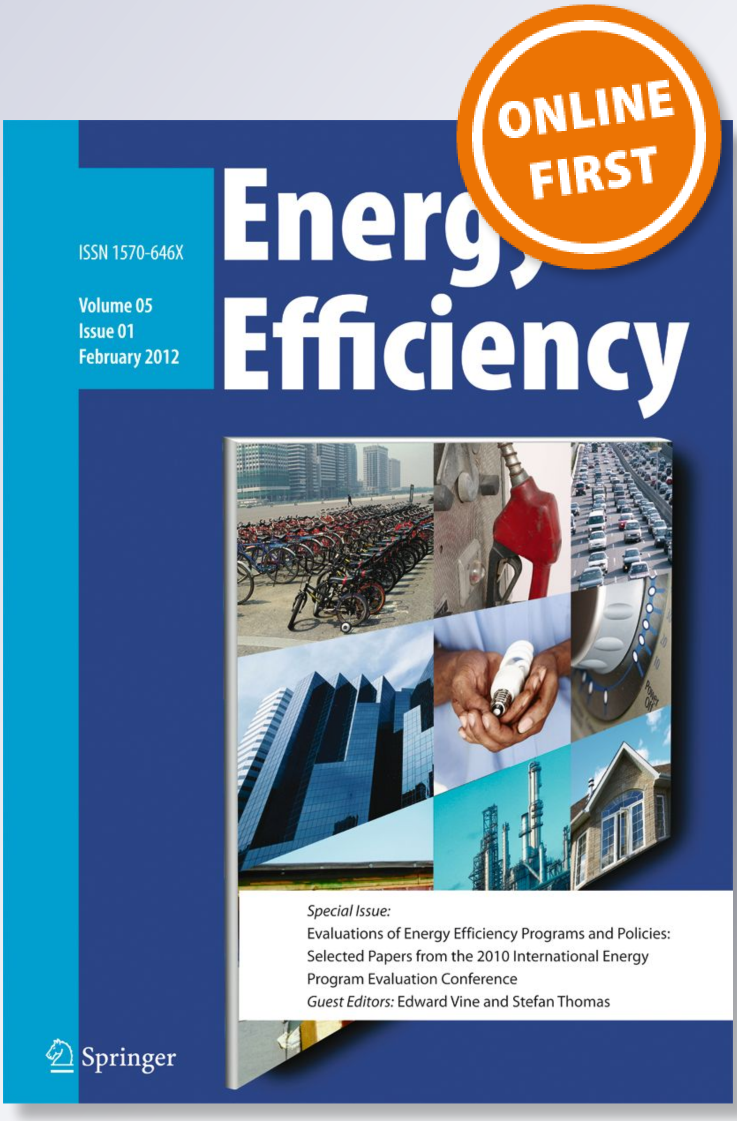

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Abstract Energy-efficient new cooking techniques have been developed in this research. Using a stove with 649±20 W of power, the minimum heat, specific heat of transformation, and on-stove time required to completely cook 1 kg of dry beans (with water and other ingredients) and 1 kg of raw potato are found to be: 710 (±24)kJ, 613 (±20)kJ, and 1,144±10 s, respectively, for beans and 287±12 kJ, 200±9 kJ, and 466±10 s for Irish potato. Extensive researches show that these figures are, to date, the lowest amount of heat ever used to cook beans and potato and less than half the energy used in conventional cooking with a pressure cooker. The efficiency of the stove was estimated to be 52.5±2 %. Discussion is made to further improve the efficiency in cooking with normal stove and solar cooker and to save food nutrients further. Our method of cooking when applied globally is expected to contribute to the clean development management (CDM) potential. The approximate values of the minimum and maximum CDM potentials are estimated to be 7.5×10^{11} and 2.2×10^{13} kg of carbon credit annually. The precise estimation CDM potential of our cooking method will be reported later.

Keywords Energy-efficient cooking with pressure cooker · Heat of transformation and on-stove-time · Solar cooking · Fresnel sheets · CDM Potential

Introduction

With ever-increasing demand for energy and consequent depletion of nonrenewable energy sources (Pastor 1988), it is imperative to focus attention on increasing efficiencies of all energy utilization processes in terms of energy and time. Wastage of energy that is more than necessary, as per thermodynamic principles, gives rise to environmental pollution due to excess green house emissions. Such excess wastages are mostly preventable by making the energy utilization processes more efficient. In African and part of Asian countries, where people mainly rely on firewood and kerosene for cooking, the increasing usages of these energy sources are having dual adverse effect on our income and environment (Ahmed and Kassass 1991; Asuamah et al. 1987; Botkin and Keller 1998; see also NASA (2010) and America's Climate Choices Panel on Advancing the Science of Climate Change, National Research Council (2010)

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on global warming). As a result, deforestation rate is on the increase (McDermott 2009). Cooking is one of the end uses of energy. Energy for cooking accounts for about 90 % of all household energy consumption in developing countries (FAO Corporate Development Repository 1997) (International Energy Agency 2006). Presently, 2.5 billion people worldwide use biomass fuels (firewood, charcoal, dung, and agricultural residues) for cooking (Federal Ministry for Economic Corporation and Development 2010). About 1.5 million people die every year from the use of biomass in cooking. It is estimated (International Energy Agency 2006, Chapter 15, P.419; www.iea.org/publications/free-publications/publication/cooking.pdf; Federal Ministry for Economic Corporation and Development 2010) that in 2030, about 2.7 billion people will use biomass. The environmental pollution and consequent global warming (NASA 2010; America's Climate Choices Panel on Advancing the Science of Climate Change, National Research Council 2010) from uses of such cooking is significant. The total amount of CO_2 emission apart from other toxic gaseous emission is then estimated to be 1.8 billion tons (see Appendix 3) annually. Moreover, a significant number of people die every day from the poor ventilation of the toxic emission arising from use biomass for cooking. As part of our ongoing research on clean developmental mechanism (CDM) for energy utilization processes, detailed experimental studies on procedures of how to reduce on-stove time and energy using new efficient cooking techniques were carried out with a view to make the energy wastages as minimum as possible. Our research, in conjunction with efficient stoves/cooker (http://www.consumerenergycenter.org/home/appliances/ranges.html http://www.youtube.com/watch?v=5qnO62VyFF8), is expected to minimize energy consumption for cooking, which if accepted worldwide, will contribute to reduction in global warming and climate changes. This paper deals only with the on-stove time and energy-efficient cooking method of dry beans and raw Irish potato. The on-stove time is defined as the minimum time cooking pot must be placed in oven or on stove or on hot plate for the cooking to be complete. There have been some researches on The Physics of Cooking (Messfolles 2011; Torok 2011; http://www.bhaslidell.com; http://www.desert.allrecipes.com). However, none deals with quantitative determination of the total minimum heat required or total amount of heat used in specific cooking processes, such as boiling, frying, sautering, etc.

In this research, we apply physics principles to develop new energy-efficient cooking method and quantitatively evaluate the minimum energy (Q_m) used in the new technique and in the conventional cooking method using pressure cooker to cook 1 kg of dry beans and 1 kg of Irish potato separately. We also determine the theoretical absolute minimum heat (h_t; called the specific heat of transformation) that is required to cook 1 kg of these items separately. The specific h_t of transformation however is a characteristic of the type of food.

We also discuss how the parameter h_t could be utilized to yield a highly improved energy-efficient cooking technique using both normal stove and solar cooker. Apart from reducing environmental pollution significantly, such improved techniques can save vital food nutrients much more than in conventional cooking techniques. As observed by Srilakshmi (2006), long duration of food subjected to excessive heat in conventional techniques destroys vital food nutrients.

The primary aim of this study is to apply physics to find out a new cooking technique that can lead to considerable savings of energy (fuel) and on-stove time over the conventional methods applied in domestic cooking the on-stove time depends on power of stove. For considerable saving of on-stove time and energy required for cooking, it has become necessary to determine Q_m including all heat wastages (Δq) due to all the heat transmission processes, and the heat of transformation, $h_t = Q_m - \Delta q$, required to transform 1 kg of dry beans to well-cooked beans product. To determine Q_m and h_t, it has become necessary to determine the power of the kerosene stove used. We used a kerosene stove with small uniform blue flame whose power was fairly accurately determined to be 649±20 W as described below.

Determination of power of the kerosene stove used

The wicks of the stove were adjusted to the same height in order to provide a low uniform blue flame so as to reduce the convective heat loss (from the space between the bottom of the pot and the flame area) as much as possible when the cooking pot is placed on the stove. By means of a funnel, kerosene was poured to a fixed mark level each time. The volume of the kerosene poured was determined using a measuring cylinder at the end of each cooking.

In the first place, certain quantity of water (50, 75, and 100 ml) was heated to complete evaporation in the same aluminum pressure cooker (with the lid open) that was later used to cook beans. The average time for complete evaporation of water was noted for each quantity of water. The mass, total emitting surface area, wall-thickness, etc. of the pressure cooker were measured. The heat capacity and the thermal conductivity of aluminum were noted from books. The emissivity of the surface was assumed to have a magnitude 1 (Eckert and Drake 1972) in the calculations. The initial (T_a) and final (T_p) temperature (both internal and external) of the pot and the on-stove time were noted for each quantity of water heated to final complete evaporation. The internal and external wall temperatures of the pressure cooker pot were found to be the same within ±1 °C because of the high thermal conductivity of aluminum. The internal temperature was noted every minute till complete evaporation of each quantity of water (see Tables 1, 2, and 3) in order to determine the radiation heat losses (see "Estimation of radiation losses" section).

Quantity of kerosene used was estimated by means of a measuring cylinder and a gauge after evaporation of water. The power of the stove was calculated using procedures in "Estimation of stove power" section. In the next section, we discuss the new method of cooking beans and Irish potato with minimum energy along with determination of specific heat of transformation.

Table 1 On-stove time and pot's internal temperature during complete evaporation of 50 ml of water in pressure cooker with lid open

On-stove time (min); t_{50}±2 s	0	1	2	3	4	4 m 38 s
Pot's internal temperature; T_i (°C)±1 °C	33	56	92	96	98	97

T_i is more accurately measured (within±1 °C) than T_p when the lid is open. So the following calculations of P_s uses T_i as recorded in Tables 1, 2, and 3

Room temperature, 35 °C; t_{50} (t_i)=278 s; volume of kerosene used, 9 ml

Table 2 On-stove time and pot's internal temperature on complete evaporation of 75 ml of water with lid open

On-stove time (min) t_{75}±2 s	0	1	2	3	4	5	5 m 54 s
Pot's internal temperature; T_i (°C)±1 °C	33	54	89	95	98	97	96

Room temperature, 35 °C; t_{75} (t_i)=354 s; volume of kerosene used, 12 ml

Materials and methods for energy-efficient cooking of beans and potato

The beans, Irish potato, as well as the ingredients were purchased from Jimeta market of Adamawa state, Northern Nigeria. The ingredients include salt, pepper, tomatoes, magi, groundnut oil, onion and kitchen spices, and finally water. Apparatuses included measuring cylinder, meter rule, weighing balance (analytical balance), thermometers, stopwatch, vernier calipers, and micrometer screw gauge; while the purchased ones are pressure cooker, kerosene stove, and kerosene.

Determination of Q_m for cooking 1 kg beans at h_t of transformation of beans

With stove set in order, as used in the evaluation of its power, the sealed pressure cooker pot containing 1 kg of washed beans, some measured amount of ingredients plus spices, along with 1.2 l of water was gently mounted on top of the burning stove. The T_a of the pot and its contents was noted. The temperature of the outside wall of the pot was noted every 2-min interval and recorded in Table 4. Immediately after hearing the fifth rocking motion (fine whistling sound), the pot (with the lid closed) was removed from the stove (Fig. 1) and transferred into a card board box (Fig. 2) whose inner wall surfaces were lined with three layers of highly reflecting aluminum foil. Sandwiched in-between the aluminum foils were plane sheets of white paper. There remained the pot (with the box closed) containing the hot food for 40 min to complete the rest of its cooking with the internal heat conserved by the Fabry–Perot type reflecting layers. The heat

Table 3 On-stove time and pot's internal temperature during complete evaporation of 100 ml of water with lid open

On-stove time (min) t_{100}±2 s	0	1	2	3	4	5	6	7	7 m 16 s
Pot's internal temperature; t_i (°C)±1 °C	32	62	82	94	96	96	98	97	96

Room temperature, 35 °C; t_{100}=435 s; volume of kerosene used, 15 ml

conservation can be understood noting the reflection and transmission of heat at different layers and knowing that the sum of the intensities of heat-reflected back into the space (where the pot is) of the box is greater than that finally going out of the layer. There is an insulating cardboard behind the layer that further blocks the transmission of the final heat rays out of the reflecting layers. At the same instant of removal of the pot from the stove, the T_p of the outside wall of the pot was noted and the stove was quickly quenched. Using the same method as employed in the evaluation of power of stove, the quantity of kerosene consumed was estimated.

We also cooked 1 kg of dry beans using the conventional method of using pressure cooker, i.e., without the insulating box. In this method, the pressure cooker pot containing the same quantities of all ingredients as above was kept on the stove till the accounting time 18 min of cooking as stated in the time table for spare ribs (Appendix 1). It is counted from the first lifting of the pressure cooker valve. The outside wall temperature of the pot was noted every 2-min interval. The amount of kerosene used was measured after removal of the pot and quenching of the fire. The data are given in Table 5.

Data collection and analysis results

Zero-cook time refers to time within 0–30 s of the first hearing of the rocking motion of the pressure cooker valve. It is called zero-cooking time in pressure cooker industry because cooking does not start before that time.

Measurement of thermal power of the stove (P_s)

The time in the last column of each of the Tables 1, 2, and 3 is the time required for the complete evaporation of water.

Estimation of stove power from data in Tables 1, 2, and 3

Appendix 2 gives definitions of all the symbols used. When the pot's outer wall T_p does not change with time, then it is nearly equal to the temperature (T_i) of the inner wall. This can be understood from the following theoretical consideration. The rate of heat transformation (q_1) from inner wall to the outer wall,

$$q_1 = K\left(T_i - T_p\right)/d \tag{1}$$

This is balanced by the heat of radiation (q_2) from the outer wall.

$$q_2 = \sigma\left({T_p}^4 - {T_a}^4\right) \tag{2}$$

where T_a is the ambient temperature=35 °C. In the present case, K_{Al}=238 W/m·K, d=3 mm=3×10^{-3}m. Thus, $q_1 = 238\left(T_i - T_p\right)/3\times10^{-3} = 79\times10^3\left(T_i - T_p\right)$, using typical value of T_p=98 °C and $q_2 = 5.67\times 10^{-8}\left(371^4 - 308^4\right)$

Balancing q_1=q_2 when T_p does not change.

$$T_i - T_p = 5.67\left((3.71)^4 - (3.08)^4\right)/79\times10^3 \tag{3}$$

Thus, $T_i \approx T_p$, due to high thermal conductivity of aluminum. This is also true when the temperature of the water is rising at a low rate of ~0.5 °C/s, as seen for the first 2 min in Table 1. This idea is used in estimating the total radiation heat loss during the evaporation of measured quantity of water so as to estimate the rate of heat supply by the stove.

Estimation of radiation losses

Let us consider Table 1. From t=0 to t=2 min, the outer T_p ($\approx T_i$) increases from 33 to 96 °C, the average rate of rise of temperature

Table 4 On-stove time and pot's external temperature (T_P) during on-stove time of cooking 1 kg of beans

On-stove time (min), t_i±2 s	0	2	4	6	8	10	12	14	16	18	19.04
Pot's external temperature; T_p (°C)±1	31	44	49	55	60	65	70	75	83	93	95

Room temperature, 32 °C; water added, 1.2 l; t_i=1,144 s; volume of kerosene used, 42 ml; m_f=2.2 kg

Fig. 1 Setup for the cooking

$$\mathrm{dT_p/dt} = 29.5\,^{\circ}\mathrm{C/\,min} = 0.5\,^{\circ}\mathrm{C}/s\tilde{}\,(i.e.,(56-33+92-56)/2 = 29.5\,^{\circ}\mathrm{C/\,min}). \tag{4}$$

The total radiation heat loss (q_{rh1}) from t=0 to t= 2 min in Table 1 is then

$$\begin{aligned} q_{rh1} &= \int \sigma A\left(T_p{}^4 - T_a{}^4\right)\left(dt/dT_p\right)dT_p \\ &=\sim \int \sigma A\left(T_p{}^4 - T_a{}^4\right)\left(1/(0.5^{\circ}C/s)\right)dT_p \\ &=\sim 2\int \sigma A\left(T_p{}^4 - T_a{}^4\right)dT_p \end{aligned} \tag{5}$$

The limits of integration being T_1 and T_2 where, T_1= 273+33=306 K and T_2=273+96=369 K.

Using data collected in Table 1, from t=2 to t= 4 min 38 s, the rate of rise of temperature was low and hence, the radiation heat loss during this time interval, q_{rh2} can be estimated from

$$q_{rh2} = \sigma A\left(< T_p >^4 - T_a{}^4\right)\Delta t \tag{6}$$

where Δt=2 m 38, s=158 s and $< T_p >= (92+96+98+97)/4 = 95.8^{\circ}C$

Thus, total radiation heat loss

$$Q_{rh}(50) = q_{rh1} + q_{rh2} = 2.64 + 7.48 = 10.12\,kJ \tag{7}$$

Quantity of heat required to evaporate 50 ml of water Q_{50} is given by

$$Q_{50} = m_{50}(100 - T_{50})c_w + m_{50}L_v + M_pC_p\left(T_p^{'} - T_a\right) + Q_{rh}(50) \tag{8}$$

Using the values of the constants given in Appendix 2, from Eq. (8) we get Q_{50}=174.6 kJ

$$Q_{75} = m_{75}(100 - T_{75})c_w + m_{75}L_v + Q_{rh}(75) + M_pC_p\left(T_p^{'} - T_a\right) \tag{9}$$

$$Q_{100} = m_{100}(100 - T_{100})c_w + m_{100}L_v + Q_{rh}(100) + M_pC_p\left(T_p^{'} - T_a\right) \tag{10}$$

Similar steps were used to obtained the following parameters for Q_{75} and Q_{100}.For 75 ml of water: $T_i - T_p = 6.99 \times 10^{-3}\,^{\circ}C;^{\circ}$ $\mathrm{dT}_p/\mathrm{dt}$=28 °C/min; q_{rh1}=2,723 J=2.7 kJ; q_{rh2}=8,371 J=8.4 kJ; $Q_{\mathrm{rh}}(75)$= 11,093 J=11.1 kJ; and Q_{75}=231.6 kJ.

For 100 ml of water: $T_i - T_p = 6.99 \times 10^{-3}\,^{\circ}C$; $\mathrm{dT_p/dt}$=25 °C/min; q_{rh1}=3,167 J=3.2 kJ; q_{rh2}= 8,172 J=8.2 kJ, at t=4 min to t=7 m 16 s; $Q_{\mathrm{rh}}(100)$=11.4 kJ; and Q_{100}=288.8 kJ.

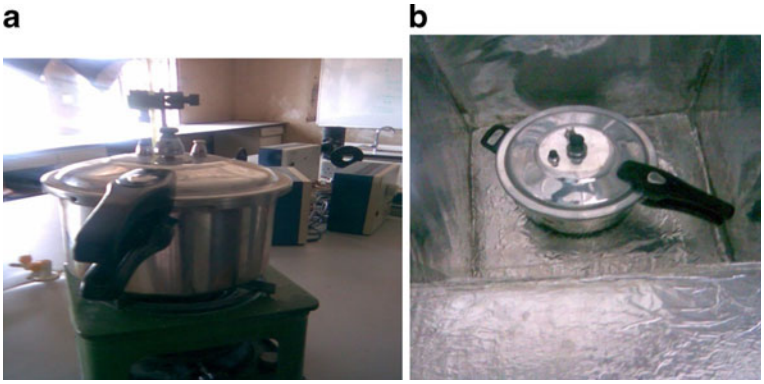

Fig. 2 **a** The simple cooking box. It really cooks all type of foods without any heat supply, once the food is first raised to 115 °C in pressure cooker and then immediately kept inside the box for about 20–40 min. **b** Pot inside new innovative cooking box. The box lid has to be closed (not shown)

Table 5 On-stove time and pot's external temperature (T_p) at complete cooking of 1 kg of beans

On-stove time (min)±2 s	0	4	8	12	16	20	24	28	32	36	40	44	48	49.03
Pot's external temperature; T_p (°C) ±1	29	42	61	74	78	81	84	86	89	92	94	96	97	97

Room temperature, 31 °C; volume of water used, 1.2 l; t_i=2,943 s; volume of kerosene used, 112 ml; m_f=2.25 kg

The average power of the stove is obtained by using equations

$$Q_r = \left(\frac{Q_{50}}{t_{50}} + \frac{Q_{75}}{t_{75}} + \frac{Q_{100}}{t_{100}}\right)/3 \tag{11}$$

where t_{50}, t_{75}, t_{100} are taken from Tables 1, 2, and 3

$$T_p^{'} = \left(T_i^{'} + T_p\right)/2 \tag{12}$$

$$P_i^{'} = (T_i + T_s)/2 \tag{13}$$

below. Thus, the average power supplied by the stove, $P_s = (628 + 654 + 664)/3 = 649W$The error in P_s is about ±20 W.

Measurement of Q_m, and on-stove time and h_t for the new technique of cooking beans

In Table 4, the total radiation heat loss is $Q_{rh} = Q_{rh1} + Q_{rh2} + Q_{rh3}$. Following the method outlined above for the determination of stove power, we find using the data in Table 4

$$Q_{rh1} = 9,664\,J = 9.7\,kJ(\textit{from time}\,t = 0\ \textit{to}\,t = 6\,\mathrm{min})$$
$$Q_{rh2} = 10,533\,J = 10.5\,kJ0(\textit{from time}\,t = 6\ \textit{to}\ t = 14\,\mathrm{min})$$
$$Q_{rh3} = 12,210\,J = 12.2\,kJ(\textit{from time}\,t = 14\ \textit{to}\ t = 19.04\,\mathrm{min})$$

Thus,

$$Q_{rh} = 32.4\,kJ$$

$Q_m = P_s t_i - Q_{rh} = 710(\pm 25)\ kJ$ and using Eq. (21) below, h_t is obtained. $h_t = 613(\pm 20)\ kJ$

Data collection with the conventional method of cooking beans with pressure cooker (with lid closed)

Following methods outlined above, q_{rh1}, q_{rh2}, Q_{rh} Q_m for conventional method of cooking were obtained as: 5.7 kJ, 86.2 kJ, 91.8 kJ, 1.82 MJ, respectively.

Equations used for calculations

P_{in} Inner pressure of the pot:

$$P_{in} = P_o + W_h/A_v = 163,992\ Pa \tag{14}$$

$T_i^{'}$ The mean internal tempt, which is equal to average sum of internal tempt, and steam tempt.

$$T_i^{'} = (T_i + T_s)/2 \tag{15}$$

$T_p{}^{'}$ The mean external tempt:

$$T_p{}^{'} = \left(T_i{}^{'} + T_p\right)/2 \tag{16}$$

Q_i Quantity of heat required to evaporate water:

$$= m_w\left(100 - T_p\right)c_w + m_w L_v + Q_{rh} + m_p c_p\left(T_p{}^{'} - T_a\right) \tag{17}$$

Q_{rh} Total radiation heat loss

P_s Average thermal power supplied by the stove:

$$= \left(\sum Q_i/t_i\right)/3$$
$$= (Q_{50}/t_{50} + Q_{75}/t_{75} + Q_{100}/t_{100})/3 \tag{18}$$

Q_N Heat required (supplied by the stove) to cook 1 kg of beans:

$$= Q_r t_i \tag{19}$$

Q_m Actual amount of heat energy used up in cooking the beans:

$$= Q_r t_i - Q_{rh} \tag{20}$$

h_t Minimum heat required to transform 1 kg uncooked dry beans to well cooked beans:

$$= \left\langle Q_m - m_p c_p\left(T_p{}^{'} - T_a\right) - \Delta m\left(L_v - c_w\left(T_i{}^{'} - T_a\right)\right)\right\rangle \tag{21}$$

m_f is the mass of the dry beans.

Note the pressure P_{in} of Eq. (14) correspond to the temperature 113.3 °C (Keenan et al. 1969)

Data collection for measurement of Q_m, on-stove-time, h_t using the new innovative technique of cooking of Irish potato with pressure cooker

Using the method indicated for q_{rh1} in Eq. 7 and Tables 1, 2, and 3.

Measurement of Q_m, on-stove-time, h_t using the conventional method of cooking (with lid closed) Irish potato with pressure cooker

Note that the pressure P_{in} of Eq. (16) correspond to the tempt, 113.3 °C (Keenan et al. 1969). Following the procedures of calculations of Q_m, and h_t, as mentioned in the case of beans, we obtain the following Table 9 Ahmed and Kassass 1991

Discussion

Using very simple physics, we have carried out an accurate estimation of the actual heat, Q_N (742.0± 25 kJ; Table 6) supplied by the stove in fully cooking 1 kg of dry beans (final mass of fully cooked product was 2.25 kg) using the innovative cooking technique. Subtracting from Q_N all the heat transferred to environment through radiation (following the procedures outlined above), we obtain Q_m, the minimum heat required to cook the beans. Subtracting from Q_m, the total heat required to raise the pot temperature, and the heat required to evaporate small amount of water, the absolute minimum heat necessary to transform 1 kg dry beans to fully cooked beans (Fig. 3) defined as, specific heat of transformation, h_t, was determined to be 613.0±20 kJ (Table 6). This last quantity is very significant for future improvement in designing new cooking vessels that can cook food with lowest heat and consequently the heating time in order to conserve energy and protect environment. The quantities determined here may somewhat depend on the type of beans and the ingredients used to make the boiled beans finally very soft, tasty, and edible. The results calculated shows that energies and time were saved almost two times (see Table 6) when using the improved technique as compared to the conventional method of using pressure cooker as per the manufacturer's manual (Appendix 1). Following the procedures mentioned in this work, h_t can also be determined for all types of food. Our research shows that these quantities depend on the type of food. For Irish potato, these quantities were also determined and given in Tables 7, 8, and 9. Even though the figures of Q_N :742.0±26 and 303±12 kJ are probably the lowest amount of heat ever used to cook 1 kg of dry beans and 1 kg of raw Irish potato, respectively, there is still room for research to improve these figures by properly designing the pot (see Fig. 4) so that all wastages of heat could be minimized in cooking with amount of heat close to the h_t value determined in this work for the two types of foods. If a newly designed pressure cooker (see Fig. 4) has a heating coil of 1 kW, then the net heating time for cooking 1 kg of beans using the above calculated heat of transformation h_t, will just be around 613±10 s. It may be mentioned that the other method of cooking using ordinary pot without pressure cooker and box requires

Table 6 Comparison of on-stove time and energy involved in the new technique and the conventional method of cooking of beans

	New innovative method	Conventional method
Time, T_i (min)	19.04±0.17	49.03±1
Q_N (kJ)	742.0±25 kJ	1.9±0.1 MJ
Q_m (kJ)	710.0±24 kJ	1.8±0.1 MJ
h_t (kJ)	613.0±20 kJ	–[a]

[a] h_t(J), by definition, is the minimum amount of heat that can transform 1 kg of dry beans in to well cooked very soft beans product (with spices and water). So, it is blank for this column

Thermal rating power of the stove, P_s=649 W±20

Fig. 3 Photograph of well-cooked beans by the new technique

Table 7 On-stove time and pot's external temperature (T_P) during on-stove time of cooking 1 kg of Irish potatoes

On-stove time (min)±2 s	0	2	4	6	7.46
Pot's external temperature; T_p (°C)±1	33	48	68	84	96

Room temperature, 35 °C; water added, 150 ml; t_i=466 s; volume of kerosene used, 15 ml; m_f=1.038 kg

three to four times as much energy and time as the conventional method of using pressure cooker. Thus, saving energy and on-stove time in domestic cooking using our method is expected to reach the level unattained by any other means of cooking so far. In the new design of the pressure cooker (Fig. 4), the heating current in the coil could be adjusted so that the total energy delivered inside the pot is just 10–15 % more than that corresponding to h_t determined in this work. It may also be switched off when the uniform temperature inside the pot reaches the maximum value of ~115 °C. In addition to the work described in this paper, we have also described fairly accurate method of determination of two important parameters.

1. Power of stove, P_s
2. Temperature inside the closed pressure cooker without using a thermometer or thermocouple
3. We have given procedures to estimate heat losses by radiation when the temperature of a vessel is changing.

It is expected that an average African family of six, using our method of cooking needs only about a gallon of kerosene for a month to cook all their food items, provided the items are kept in warmers before consumption. Normally, they use three to six gallons of kerosene every month for cooking. Application of the new technique of cooking along with energy-efficient stoves could be a solution to felling trees indiscriminately in third world countries. This in turn will have twofold beneficial effects: (1) reduction in global warming; (2) increase in agricultural output through forest preservation. Other minor benefits include reduction in fire accident rates with reduction in use of heat.

Table 9 Comparison of on-stove time t_i and Q_m required in the new technique and the conventional method of cooking Irish potato

	New innovative method	Conventional method
Time, T_i (min)	7.46	17.51
Q_N (J)	303 kJ±12 kJ	691 kJ
Q_m (J)	287 kJ±12 kJ	497 kJ
h_t (J)	200 kJ	–[a]–

[a] h_t(J), by definition, is the absolute lowest amount of heat energy (from stove) required to cook 1 kg of potato. Therefore, it is absent in the conventional method, since the corresponding calculated value, 407 kJ far exceeds that of the new innovative method and by definition it is not h_t(J)

Thermal rating power of the stove, P_s=664 W

The results of this investigation can find many applications in restaurants and kitchen, especially, for saving energy and on-stove cooking time. Efficient stoves (VITA 1985) can make a big difference. Some efficient stoves (http://www.consumerenergycenter.org/home/appliances/ranges.html; http://www.youtube.com/watch?v=5qnO62VyFF8) can cook 15 lbs of pinto beans only with 0.7 kg bamboo. However, if our method is adopted, the energy consumption and the stove time can be reduced further by nearly 50 %. This present method cooking technique does not only help in saving energy and on-stove time, but it also helps in conserving the vital food nutrients and in minimizing emission of harmful product into the environments and thus contributes towards reduction of global warming(NASA 2010; America's Climate Choices Panel on Advancing the Science of Climate Change, National Research Council 2010).

Efficiency of the stove used The efficiency of the stove η can be defined as $\eta_{st} = (Q_N/H) \times 100$ where Q_N= total amount of heat required to boil off completely a given mass of water. H=total high heating value of the net amount of fuel used to boil off the water. From the data presented in Tables 1, 2, and 3 and using the high heating value of kerosene[10c], the average efficiency of the stove during boiling the three quantities of water

Table 8 On-stove time and pot's external temperature T_p at complete cooking of 1 kg of Irish potatoes using conventional method

On-stove time (min)±2 s	0	2	4	6	8	10	12	14	16	17.51
Pot's external temperature; T_p (°C)±1	31	41	51	60	68	78	86	93	94	94

Room temperature, 33.3 °C; volume of water used, 150 ml; t_i=1,041 s; volume of kerosene used 39 ml

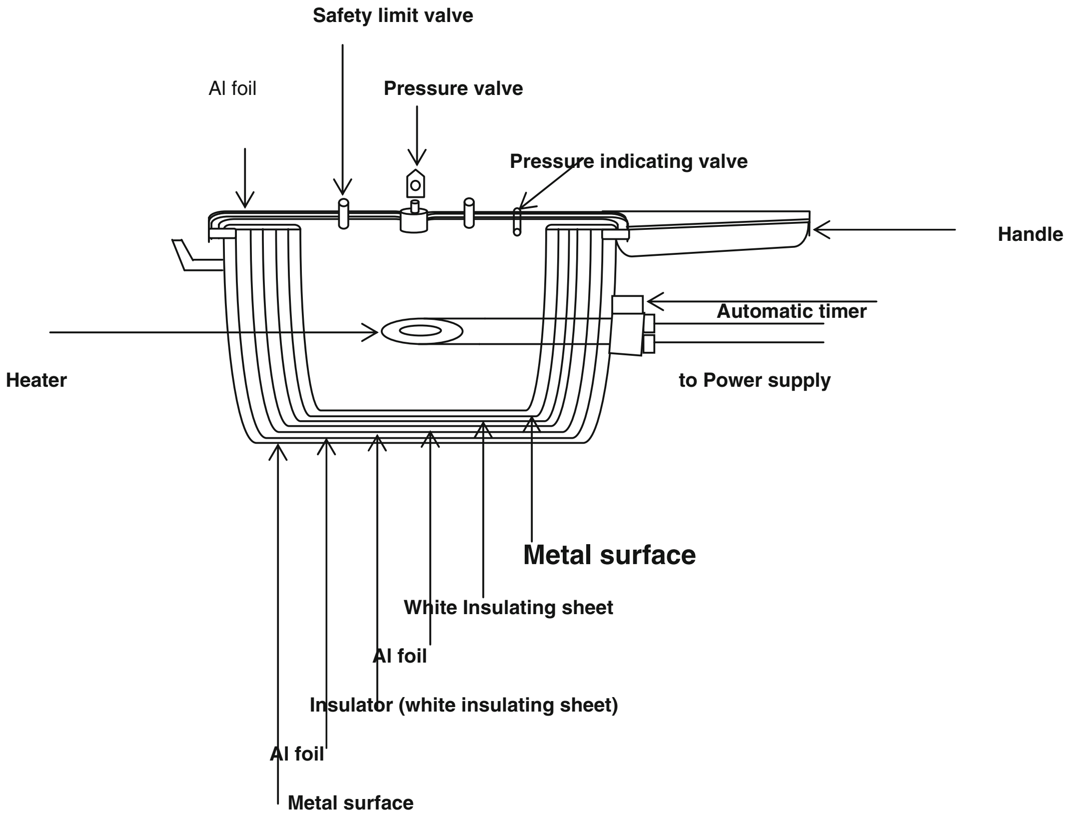

Fig. 4 New design of automatic electric timer pressure cooker that can cook food with lowest heat energy

were calculated to be 54.0, 52.3, and 51.5 % and thus on the average 52.6±2 %. This stove efficiency (η_{st}) is however is different from the cooking method efficiency (η_{cm}) as defined below.

Applications of our findings in designing new solar cooker

The main reasons why solar cooker has not been popular in the world specially, in Africa where sunshine is abundant are:

1. It takes 3.5–5 h to cook 1 kg of beans when sunshine is intense and abundant.
2. The solar cooker is bulky, costly, and not easily transportable. Many designs are not durable.
3. The solar cooker is ineffective with low sunshine.

All these factors can be eliminated in the new design of solar cooker that uses the above findings and the following additional ideas:

Transparent Fresnel sheets (Norman 1980; http://waylowbargains.ecrater.com/p/10120367/5; http://www.instructables.com/id/solar_oven) can be used both on the top and the side facing the sun to focus sunlight in solar cooker of trapezoidal structure (with bottom area about 1/8th of the top area) on to blackened absorbing base materials (on which the cooking pots can be placed once the temperature rises to above 250 °C). At that point, if the pressure cooker pot containing 1 kg of dry beans (with 1.2 kg of water and other ingredients) is placed inside such a solar oven, the time to reach temperature of 115 °C inside the pot will be around 35 min with a constant solar insolation of 500 W/m^2. Based on our above findings, the pot then can be removed and transferred to a well-insulated pot for the food to be cooked by the internal heat. If needed, the temperature can be reduced by adjusting the Fresnel sheets on the top face. Because of much higher temperature inside such a solar cooker the heat transfer (to the pot) efficiency will be higher resulting in very time-efficient solar cooking system. Once the pot is removed after about 35 min, fresh pot of raw food can be placed inside the solar cooker. Detailed research on such new solar cooking technology will be reported separately.

It may be mentioned that cooking is a one-way process unlike a cyclic one through which engines operates. Unlike the case of an engine, in this process, part of the heat absorbed by the system (the pot containing food product) does not necessarily have to be released to the environment until at the end when we want the cooked product to be cooled for consumption. Thus, physics allows the cooking system to be made more efficient than it exists today.

Efficiency of the present method of cooking and comparison with conventional methods of cooking

Ideally, the efficiency, of a cooking method should be defined by the equation: $\eta_{cm} = 100 \times h_t / Q_N$. Where as defined earlier, h_t=minimum heat required to cook 1 kg of a food material, i.e., to transform 1 kg of raw food with required ingredients into a completely cooked food product and Q_N=total amount heat supplied by the stove for the cooking process. While values of Q_N have been determined by several workers' knowledge of h_t is not available for all types of food materials. In Table 10, we have given η for new and conventional methods used in this research for both beans and potato.

We do not have data (from literature) on h_t of other food items. As defined earlier, h_t is expected to be independent of cooking method and is a characteristic of the food items only. Even though Q_N of cooking methods employed by other workers might be available, because of non-availability of data on h_t, it has not been possible to compare the efficiency of our cooking methods with those employed by other workers in researches. It may be mentioned that a cooking method would be 100 % energy efficient if it can cook the food with energy mh_t, where m is the mass of the food item in kilogram. It is not impossible thermodynamically to achieve this targeted efficiency, for which more research is necessary.

Table 10 Comparison of efficiencies of cooking methods

Type of food	Efficiency (%) of present new method of cooking	Efficiency (%) of conventional method of cooking used in this work
Beans	87	32
Irish potato	67	30

It may be mentioned that the amount of energy used in this research in cooking beans and potato are the lowest so far when compared to those available in literature. For example, Carlsson-Kanyama and Boström-Carlsson (2001) carried out extensive researches on energy required in cooking different food items. The minimum energy used by them was 1.5 MJ/kg for cooking potato. Let us compare with the findings in Table 8 where we see that 1 kg of Irish potato was cooked with total energy input of 303 kJ whereas the h_t for potato is 200 kJ. Thus, our method of cooking is by far energy efficient and energy saver compared to any other method used so far. It is needless to mention that all the cooked beans products reported here were happily consumed by a number of postgraduate students of this university.

Contributions of the present research to the CDM potentials

Obviously, if the results of the present research are applied worldwide to cooking, it will give rise to a significant savings of energy and thus carbon emission. It thus will reduce environmental pollution significantly. In other words, it has CDM potential. To quantify precisely the CDM potential of the present research when applied to cooking worldwide is beyond the scope of the work. However, we have approximately estimated the minimum and the maximum CDM potential as follows:

Minimum CDM potential In India (Khennas 1994) approximately 2.5 l of kerosene is used per person per month. Emissions from kerosene stove (with blue flame) is lower by a factor of 3 when compared to biomass (Wijaytunga and Attalage 2002). To estimate the minimum CDM potential, we assume that globally everybody is using kerosene for cooking at the rate of 3.0 l per person per month (assuming six persons per family). The total annual usage of kerosene for cooking=7×10^9 (global population)$\times3.0\times12=4.3\times10^{11}$l. The carbon factor (www.carbonrationing.org.uk/wikicarbon-conversion-factors) for 1 l of kerosene is 2.331 kg of CO_2 emission. Thus, the total minimum annual global carbon emission from cooking (if kerosene is used)=$2.331\times4.3\times10^{11}=1.0\times10^{12}$kg.

If our method is used for cooking globally, at least 75 % of the energy will be saved. Thus, the total minimum CDM potential=$0.75\times1.0\times10^{12}=7.5\times10^{11}$kg.

Thus globally, a minimum of 7.5×10^{11} kg carbon emissions could be saved if our method is used in cooking.

Maximum CDM potential of our cooking method The global energy usage in 2010 stands at 510 quadrillion British thermal unit (BTU; FAO 2012). One BTU is 1,055 J of energy. We assume that 10 % of this energy is used for cooking globally. Thus, the total global energy use for cooking is $510\times10^{15}\times1{,}055\times0.10$ J= 5.4×10^{19} J. One kilowatt hour has a carbon factor of 0.2; 1 kWh=$1{,}000\times3600=3.6\times10^{5}$ J. Thus, the total maximum annual CDM potential is 5.4×10^{19} J$\times0.75\times$ 0.2 kg/(3.6×10^{5} J)=$0.33\times10^{14}=2.2\times10^{13}$ kg.

Contributions of improved cooking methods to the CDM potential depend on the product of η_{st} and the η_{cm} of the cooking methods. A lot of research works have been carried out on improving efficiency of stoves using renewable energy sources. Panwar and Rathore reported an improved wood stove designed to run on biomass gasification with an efficiency of 26.5 % (Panwar and Rathore 2008). Improved wood/biomass stoves currently run on thermal efficiency of 25–35 %. According to Prof. P. D. Grover of the Indian Institute of Technology, Delhi, possibility of significantly improving the efficiency to 65 % exists (http://www.repp.org/discussiongroups/resources/stoves/Grover/paper-grover.htm). Reed and Larson (1996) discussed an improved version of wood–gas stove for developing countries using an inverted downdraft gasifier that produces 1.2–3.0 kW with biomass input of 4–10 g/min. The system also produces 20–25 % charcoal. Panwar (2009) and Panwar et al. (2009) carried out experimental investigation of open core down draft biomass gasifier oven for food processing industry (especially for baking operation) that can save 33 t of CO_2 emission in 3,000 h of operation. Panwar (2010) carried out studies on gassifier stove and double pot-improved household cook stove developed in Sardar Patel Renewable Energy Research Institute (SPRERI) gasifier stove and double pot-improved household cook stove. The stoves were tested with *Jatropha* shell. Thermal performance and pollutant emissions during water boiling test were evaluated. *Jatropha* shell combust properly in SPRERI gasifier stove and thermal efficiency was recorded about 31.10 %. In case of double-pot improved cook stove mixed fuel (1:1), *Jatropha* shell and babul wood was used by them for testing and its thermal efficiency was about 22.88 %. Lower pollutant emissions were recorded in double-pot improved cook stove as compared to SPRERI gasifier stove.

As mentioned earlier, total energy savings from cooking depends on the product of efficiencies of cooking stove and cooking methods. Thus if our energy-efficient cooking methods are applied along with efficient stoves as mentioned above, the emissions of carbon dioxide and toxic gasses from cooking would become minimum globally and cooking can be done with minimum use of energy. Thus, a huge amount of energy can be saved globally in cooking which can be diverted to other useful works apart from cooking. This will contribute significantly not only to reduction of environmental pollution but also to the reduction of global warming (NASA 2010; America's Climate Choices Panel on Advancing the Science of Climate Change, National Research Council 2010; McDermott 2009), saving thus our environments and atmosphere.

Recommendations for further work

- The insulation of the box can be further improved by using stereo foam. The food then can be kept warmer much longer. The time inside the box for complete cooking can also be somewhat reduced.
- Design of a new commercial automatic electric pressure cooker, which can conserve more heat than any existing ones. A design of such cooker that can well utilize one of the very important findings in this research (i.e. h_t(J)) is shown below (Fig. 4). It can be arranged such that the total heat supply is just 1.1 h_t(J) (i.e., 10 % extra heat is supplied to take care of food sample variations). The cooking pot will be highly effective if the space in between the two metal walls (Fig. 4) could be made vacuum and highly reflecting (as in good thermoflux), instead of putting the metal foil and white paper sandwiches. This however would make the pressure cooker pot very costly. To keep the cost low while providing good effective insulation, the design shown in Fig. 4 is sufficient. The heating coil can also be encapsulated in a cylindrical stainless steel tube running vertically through the centre to protect it from chemical reactions with food items.
- We recommend that research be carried out on precise estimation of global CDM potential of our energy-efficient cooking technique described in this work. This can be done first by estimating precisely the total energy used globally for cooking.

Appendix 1

Reference cooking time table (accounting time from first exhausting gas of cooking (i.e., first whistling))

Food name	Food (kg)	Water (kg)	Cooking time (min)	Cooking situation	Remark
Rice	1.5	1.2	5	Done	
Porridge	0.2	2	10	Done	Natural cool
Spareribs	1	0.6	15–18	Done meat	Natural cool
Pig leg	1	0.8	20–25	Done meat	Slice
Old chicken	1.5	1	25	Cut meat off bones	Slice
Young chicken	1	0.6	20	Cut meat off bones	Whole chicken
Pork	1	0.5	15	Done meat	Slice
Beef	1	0.6	15	Done meat	Slice
Lamb/goat	1	0.8	15	Cut meat off bones	Slice
Fish	1	0.45	10		Cutting piece steam

Multi-insurance safe type aluminum alloy Pressure Cooker Company Ltd. (Shunjin)

Appendix 2

Variables that are constant and were used where necessary

σ	Stefan–Boltzmann constant (5.67×10^{-8} W/m^{2}K)
L_v	Latent heat of vaporization (2.26×10^6 J/kg or 540 cal/kg)
c_w	Specific heat capacity of water (4,200 J/kgK)
c_p	Specific heat capacity of the pot (896 J/kgK; Eckert and Drake 1972)
P_o	Atmospheric pressure (101,325 Pa)
ε	Emissivity of the pot (assumed to be 1)
g	Acceleration due to gravity (10 m/s^2)

Variables that are directly measured

m_p	Mass of the pot with cover (1.45 kg) and without cover (0.85 kg)
h	Height of the pot (14 cm)
r	Radius of the pot (10 cm)
d	Thickness of the pot (3 mm)
r_n	Nozzle's valve radius (0.19 cm)
m_h	Mass of the head of pressure limit valve (71.1 g)
T_p	Pot's external temperature (degree Celcius)
T_a	Initial temperature of the pot (degree Celcius)
T_i	Pot's internal wall temperature after on-stove time (degree Celcius)
t_i	Total on-stove time
m_w	Mass of water used
m_f	Mass of rice plus water after time t_i of cooking
Δm	Amount of water lost ($\approx 10^{-3}$ kg)

Variables that are calculated

A_v	Area of the nozzle's valve: $\pi r^2 = 1.135 \times 10^{-5} m^2$
A_p	Area of the pot=$2\pi rh = 0.088$ m^2
W_h	Weight of the head of pressure limit valve: mg=0.711 N

Appendix 3

The approximate estimation is made as follows: according to Sohel et al. (Ref. a) the approximate firewood (biomass) consumption for a family in Bangladesh for cooking can be taken as 6.5 kg per family. This translates to roughly 1 kg per person per day. Now it is estimated (Ref. b) that in 2020, approximately 2.7 billion people will be dependent on biomass for cooking. Using the carbon factor of firewood as 1.835 (Ref. c) we estimate the total CO$_2$ emission to be = $2.7\times 10^9 \times 1kg \times 1.835 \times 365 = 1.8 \times 10^{12}kg$.

Ref. a: SI Sohel, P Rana, and Syma Akther. Linking biomass fuel consumption and improved cooking stove: a study from Bangladesh.www.worldenergy.org/doments/congresspapers/65.pdf

Ref.b: gtz/HERA-Household Energy Programme. energy for cooking in developing countries, chapter 15, p. 419. www.iea.org/publications/freepublications/publication/cooking.pdf

Ref.c: Rupert Oliver Forest Industries Intelligence Ltd for AHEC. Carbon factor of forest wood. A preliminary assessment of the carbon foot print of American hard wood Kiln dried lumber supplied to distribution in the European Union. 4 March 2010

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